RR 66-79

ENCAPSULATING FLATPACK INTEGRATED CIRCUITS BY MEANS OF ULTRASONIC WELDING

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ABSTRACT

Ultrasonic welding of covers onto flatpack integrated circuits was investigated, in order to develop a method of producing hermetically sealed packages at high rates without exposing them to high temperature. Ultrasonic welds of the proper geometry were readily achieved between the desired materials, and leaktight packages were produced using flatpacks that had been prepared to provide a flat welding surface. With smaller and unprepared flatpacks, leaktight packages were not reproducibly effected, since welding machine settings required for complete cover bonding to the irregular surface of the flatpack frame resulted in fracture of the fragile glass seal.

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I. INTRODUCTION

The objective of this work was to demonstrate the production practicability of assembling flatpack integrated circuits by ultrasonically welding covers on flatpack frames.

Current techniques for hermetically sealing certain flatpack configurations usually involve resistance welding or furnace soldering of the covers. However, processing by these techniques is slow and expensive, and reliability and reproducibility are not adequate. Resistance welding requires the use of a costly castellated frame to provide electrical connection between the top frame and the base. This process involves stitching the cover with a series of overlapping welds, and several minutes may be required to complete a single assembly. Rejects because of leakage through one or more of the welds may be as high as 15-25 percent. Furnace soldering is considerably faster and more reliable, but the elevated temperature necessary to melt the solder may be higher than the operating temperature of the circuit and can damage sensitive circuit components.

Ultrasonic welding offers a means for encapsulating flatpack circuits at a fast rate without external heating. Welding is accomplished by clamping the workpieces between an ultrasonically driven welding tip and an anvil, so that the material undergoes cyclic stress resulting from the superimposition of vibratory excursion on static force. The cyclic excursion is parallel to the plane of the weld interface, and the moderately low static force is normal to this plane.

Two types of ultrasonic welding techniques were projected for the flatpack closure: torsional or ring welding, and line welding. Line welding, which is essentially spot welding with a greatly elongated tip,, would permit sealing a rectangular package with four welds at right angles. This approach was not pursued, however, because it involved a multiple weld operation, whereas torsional welding is accomplished with a single weld pulse.

Torsional welding, originally developed for making circular welds, has proved equally effective for other geometries involving closed peripheral welds, including ovals, squares, and rectangles. In this process, the components to be joined are clamped between a welding tip, contoured to the desired weld geometry, and a supporting anvil, and the tip executes torsional vibratory excursions in a plane parallel to the weld interface. The result is a complete circumferential weld produced in a single weld interval of generally less than one second. Such welds in a variety of geometries, sizes, and material combinations have proven to be helium leaktight to a limit of about 10^{-10} cubic centimeters per second at STP.

Although torsional welding was used for much of the work described herein, one other technique was employed and showed promise with the diminutive flatpacks used. Ultrasonic lateral-drive welding was accomplished with a welding tip having a solid face, of a size sufficient to cover the entire frame of the flatpack. This tip, mounted on the primary coupler of a longitudinally driven transducer-coupling system, executed lateral vibratory excursions in a plane parallel to the weld interface. With this arrangement, the top surface of the flatpack frame defined the circumferential weld area.

II. MATERIALS

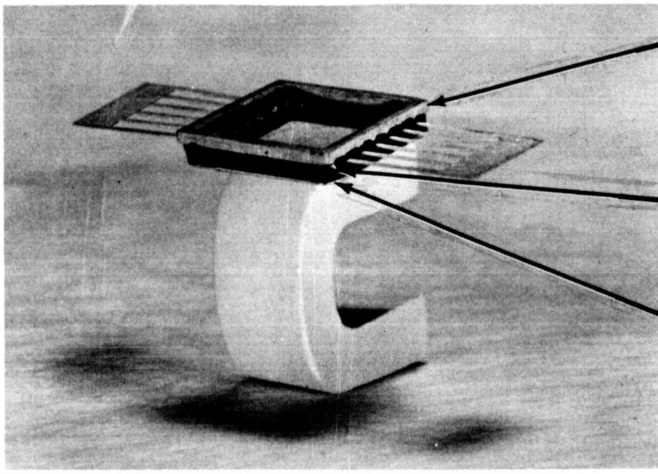
A. Flatpacks

Welding was carried out with two types of flatpacks. The larger flatpack, 3/8-inch-square, was used for initial investigations to ascertain tooling requirements and to consider problems associated with flatpack geometry and construction, since standard laboratory equipment could be readily modified to permit work with these dimensions. The smaller, rectangular flatpack, 1/4-inch-x-1/8-inch, was used for final sample preparation and evaluation.

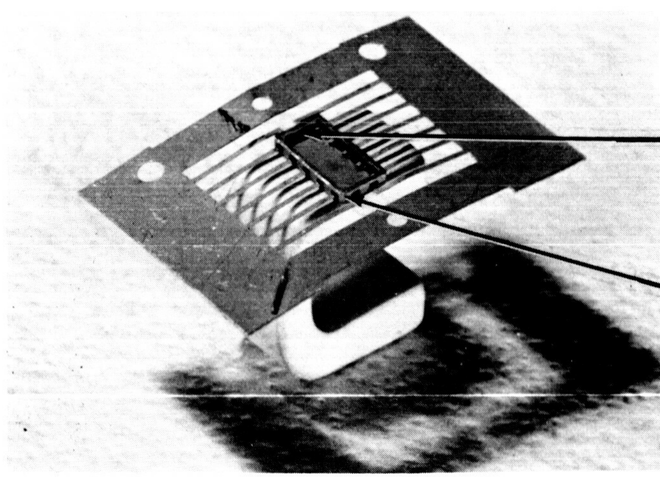
As shown in Figure 1, both flatpacks had bases and top frames of gold-plated Kovar and gold-plated Kovar leads sealed with glass. In the larger flatpack, the glass formed a spacer between the base and frame, whereas the smaller flatpack had a Kovar body of a castellated design, metallurgically bonded to the base, and the glass served only to seal the leads. This latter design offers greater structural rigidity.

Thickness measurements on the frame of the 3/8-inch-square flatpack showed an average thickness of 0.038 inch, with variations as great as ±0.0025 inch. The 1/4-x-1/8-inch flatpack measured 0.034 inch thick, with variations of ±0.0015 inch. As noted later, these variations, resulting chiefly from non-parallelism of the top and bottom faces, introduced alignment problems and sometimes prevented complete peripheral contact of the welding tip with the surface to be welded.

A quantity of 150 Westinghouse 3/8-inch-square flatpacks, together with 150 gold-plated Kovar covers, were procured from Zell Products Incorporated, Norwalk, Connecticut. A total of 149 of the 1/4-x-1/8-inch flatpacks, manufactured by Texas Instruments, were procured: 49 through the Goddard Space Flight Center, 80 from Texas Instruments domestic plants, and 20 with mounted semiconductor wafers from the Texas Instruments plant in England.



3/8-Inch-Square Frame
(Westinghouse Flatpack)



1/4-x-1/8-Inch Frame
(Texas Instruments Flatpack)

Figure 1

FLATPACKS USED IN THIS PROGRAM

B. Cover Materials

The following cover materials were used with the respective flatpacks:

Flatpack	Material	Gage (inch)
3/8-inch-square	Aluminum alloy 3003-H18	0.006
	Aluminum alloy 1145-O	0.006
	Kovar, gold-plated	0.010
	Copper, commercially pure, annealed	0.005
	"A" nickel, 500μ-inch gold plating	0.006
	Alloy 180 (22% copper, 78% nickel)	0.010
1/4-x-1/8-inch	Aluminum alloy 3003-H18	0.005
	Aluminum alloy 1145-H19	0.004
	Aluminum alloy 5154-H18	0.006
	Nickel, gold-plated	0.005
	Kovar, gold-plated	0.005 0.003

In an effort to improve bonding, foil interleaf materials were inserted between the cover and the frame. Three interleaf materials were used with the 3/8-inch-square flatpack: 0.0005-inch gold, 0.00015-inch gold, and 0.0003-inch 1100-H14 aluminum alloy. Gold-germanium preform interleaves were used with the 1/4-x-1/8-inch flatpack.

C. Materials Preparation

Prior to welding, the mating surfaces of the flatpacks and covers were wiped with perchloroethylene or acetone. In addition, the larger flatpacks were ground on their bottom surfaces and in some instances hand-lapped on the top surfaces to minimize thickness variation (Section V).

III. ULTRASONIC WELDING EQUIPMENT

Ultrasonic welding of the larger flatpack was carried out with an available laboratory torsional welder operating at a nominal frequency of 15 kc. For the smaller flatpack, both a 28-kc torsional welder and a 17.5-kc lateral drive welder were used.

A. 15-kc Torsional Welder

The 15-kc laboratory-model torsional welder (a forerunner of the commercial model shown in Figure 2) used for the larger flatpacks was equipped with six magnetostrictive nickel-stack transducers which had a total power-handling capacity of 10 kilowatts. These transducers delivered longitudinal vibration through wedge-shaped couplers to tangential points on a vertical reed member, which thus executed torsional vibration. A hydraulic system permitted application of clamping force to the weld members through the anvil assembly.

The welder was modified to incorporate an impedance-matching coupler and annular welding tip to accommodate the flatpack geometries. The tip was flat-faced since the flatpack frame defined the weld area, although contoured welding tips are generally used for annular welds. A flat-faced anvil was used.

Checkout of the welder was carried out with coupons of aluminum alloy, copper, and nickel, each material welded to itself. Representative welds between coupons of 0.012-inch 3003-H18 aluminum alloy (made at 1000 watts power, 400 pounds clamping force, and 0.3 second weld time) proved to be helium leaktight, indicating satisfactory performance.

B. 28-kc Torsional Welder

It appeared advisable to use a higher frequency system for welding the smaller flatpacks. An increase in frequency dictates a physically smaller system and, with torsional vibratory systems, permits a smaller minimum weld diameter; calculations indicated that 28 kc would permit a minimum diameter of approximately 0.15 inch, compared to approximately 0.4 inch for the 15-kc system.

A higher frequency system offers another advantage for torsional welding of flatpacks of the current design, in which the glass or ceramic used to seal the leads has a strain limit beyond which cracking may occur. The analysis in Appendix I indicates that the power that can be applied for

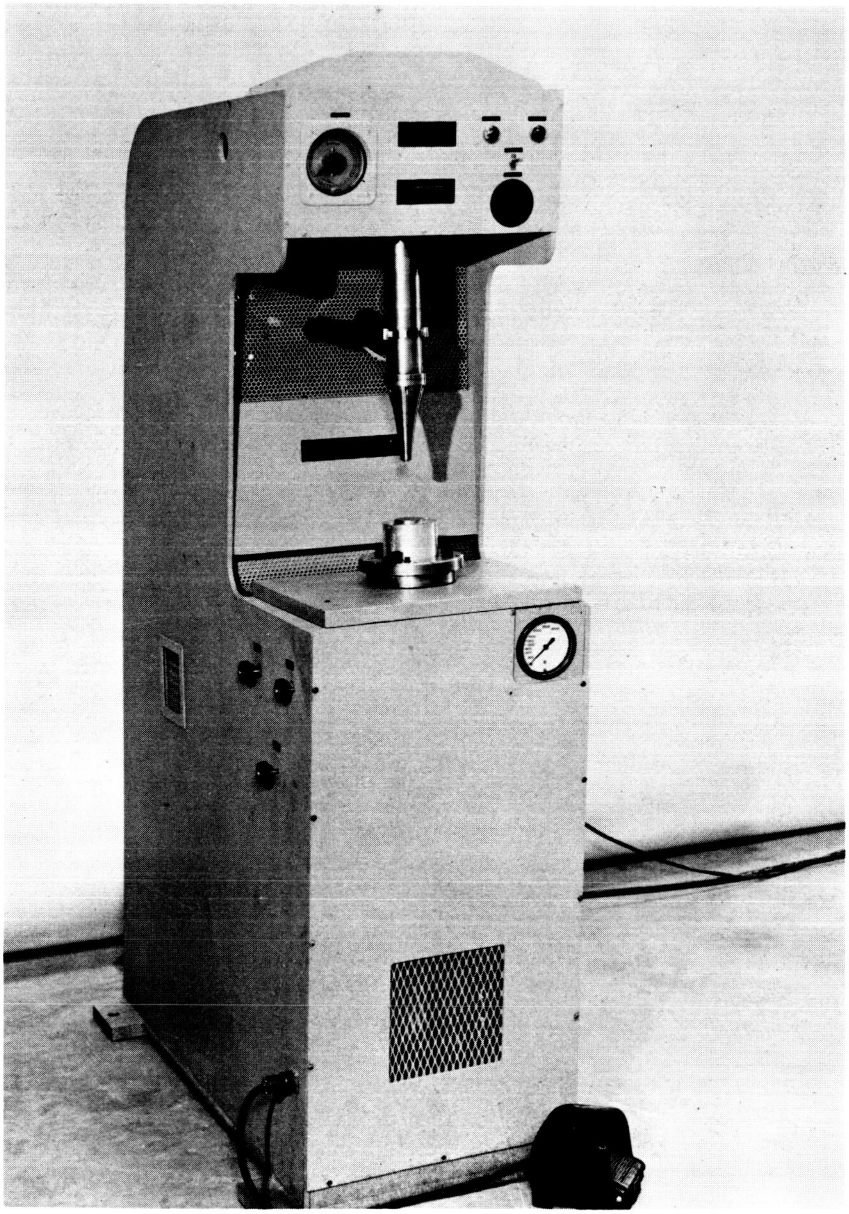


Figure 2

STANDARD COMMERCIAL 15-KC TORSIONAL WELDER welding is proportional to the square of the frequency when other variables are constant. Thus by approximately doubling the frequency (from 15 kc to 28 kc), the power is increased nearly four times for the same vibratory strain applied to the glass seal.

For these reasons, the laboratory-type 28-kc torsional welder shown in Figure 3 was assembled for use with the smaller flatpacks. This system incorporated four nickel-stack transducers, having a total power-handling capacity of 1200 watts. It was expected that this power would be adequate for the required weld area (approximately 0.04 square inch). The welder incorporated a hydraulic clamping force system.

A welding tip contoured to the flatpack frame geometry was designed as shown in Figure 4.

C. 17.5-kc Lateral-Drive System

This system, assembled from existing components and adapted for welding the smaller flatpacks, was activated by a nickel-stack transducer which had a power-handling capacity of 2 kilowatts. The transducers delivered longitudinal vibration through a lateral coupler to the welding tip, which executed lateral vibration. The array was equipped with a flat welding tip having a surface area defined by the flatpack frame.

The system was mounted on a trunnion, as shown in Figure 5, and force was applied by a hydraulic cylinder which reacted through the mounting pivots. This mounting and force application system was found unsatisfactory for flatpack welding; parallel alignment between the welding tip and the anvil surface could not be maintained, and the rate of force application was difficult to control.

To solve the alignment problem, a precision anvil fixture was designed to provide accurate positioning of the 1/4-x-1/8-inch flatpack and also to provide restraint against rotational movement of the flatpack during welding. Figure 6 shows the fixture mounted on the anvil of the lateral-drive welder in such a way that the direction of vibration is perpendicular to the long sides of the flatpack.

D. Checkout of Welding Systems

The 28-kc torsional welder and the lateral-drive welder were evaluated with 1-inch-wide coupons of 0.005-inch aluminum alloy. Table I presents the results of tensile-shear strength tests on these welds. In all cases, weld strength was sufficient to induce failure of specimens by tearing out the weld region rather than by shearing or peeling the weld itself, indicating satisfactory performance of both welders.

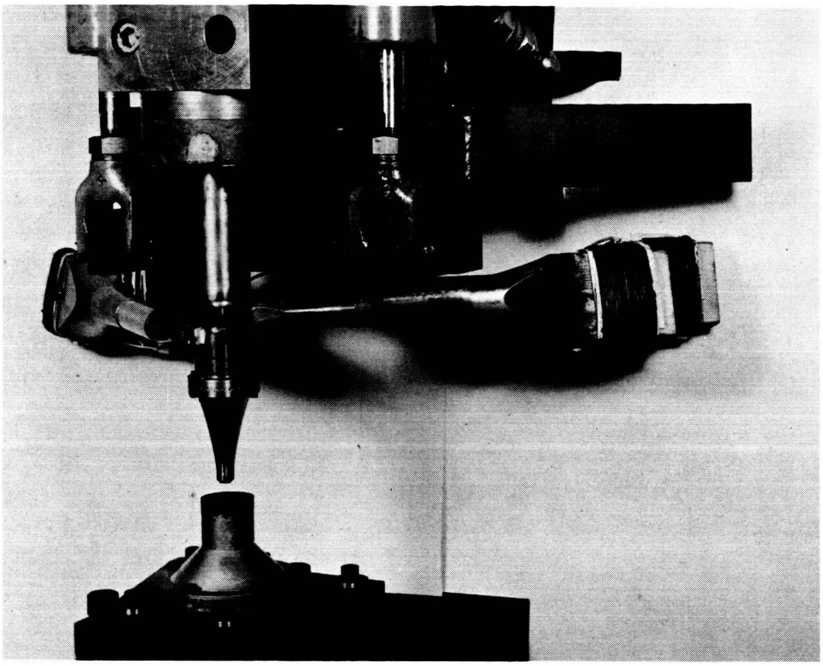


Figure 3

28-KC TORSIONAL WELDER

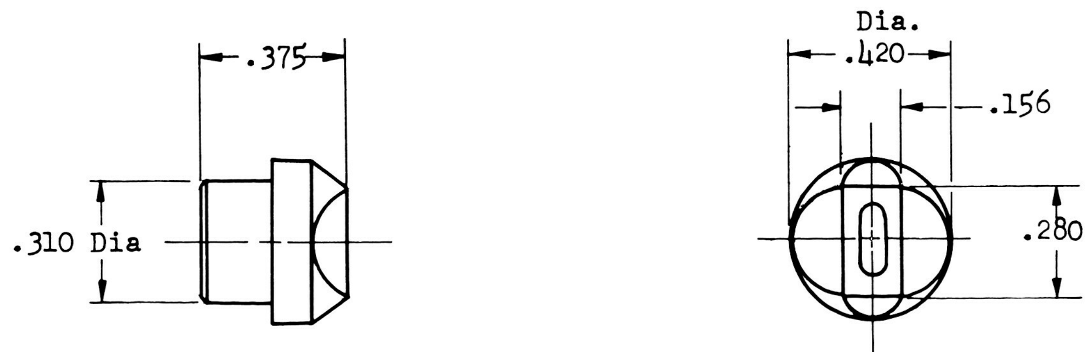


Figure 4

WELDING TIP FOR USE WITH THE 28-KC TORSIONAL WELDER ON THE 1/4-x-1/8-INCH FLATPACK

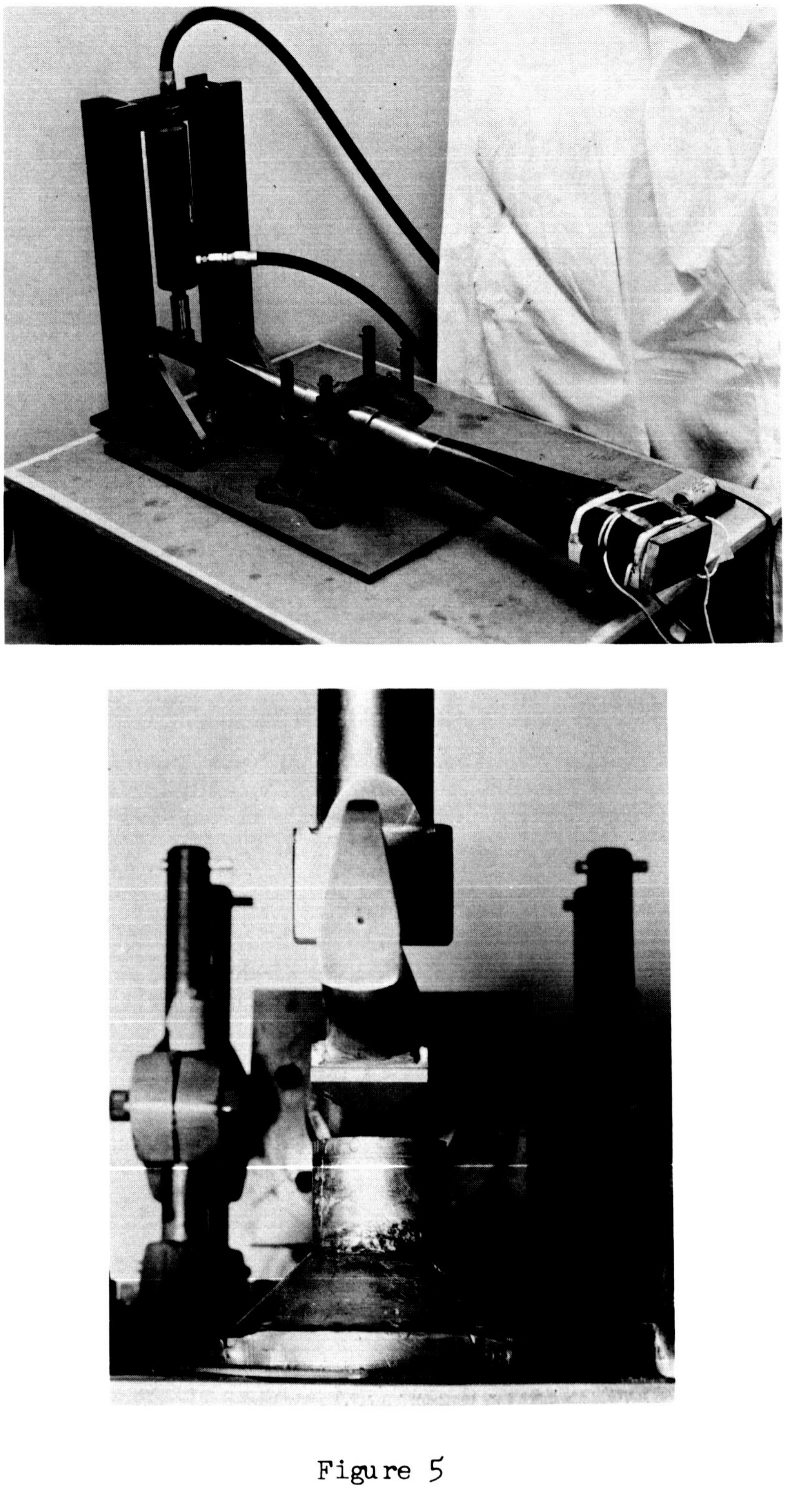


Figure 5

17.5-KC LATERAL-DRIVE WELDER IN ORIGINAL MOUNT

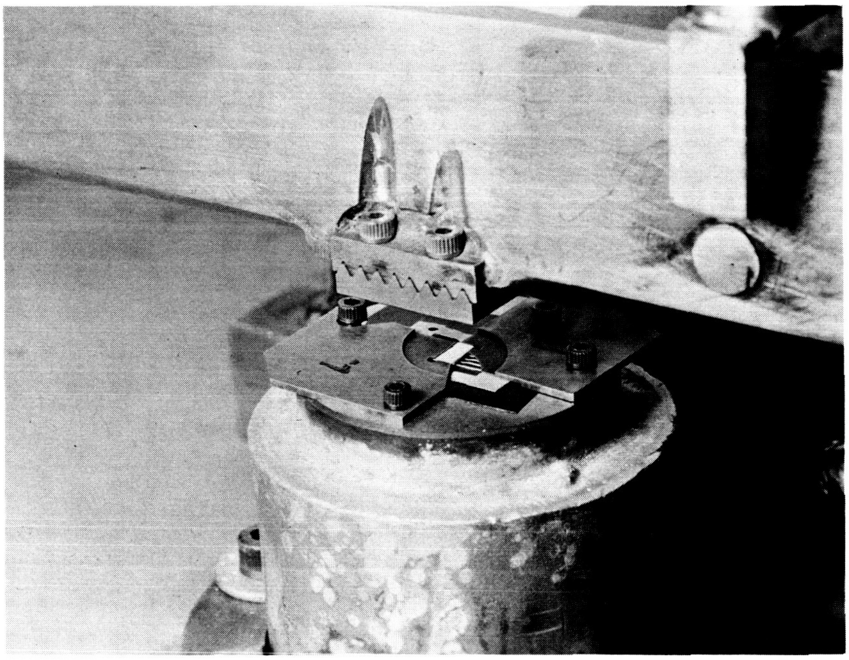


Figure 6

PRECISION ANVIL FIXTURE FOR 1/4-x-1/8-INCH FLATPACK

Table I

WELD STRENGTHS OF 0.005-INCH 3003-H18 ALUMINUM
WELDED TO ITSELF

System	Power (watts)	Clamping Force (lbs)	Time (sec)	Weld Strength (lbs)		
				Max.	Min.	Av.
28-kc Torsional (annular tip)	600	200	0.1	62	55	60.5*
28-kc Torsional (rectangular tip)	800	400	0.3	56	37	49.9*
17.5-kc Lateral-drive	850	320	0.4	72	72	72*
17.5-kc Lateral-drive	850	320	0.3	73	71	72*
17.5-kc Lateral-drive	850	320	0.5	73	69	71*

* Failure of specimen occurred in parent material.

E. Precision Welder Frame and Force System

The hydraulic systems of the 28-kc torsional welder and the 17.5-kc lateral-drive welder were not capable of sensitive force application within the low clamping force range (200-300 pounds) required for welding flatpacks. Furthermore, alignment problems with the lateral-drive system had not been solved, even with the precision anvil fixture. Satisfactory weld data could not be developed on the smaller flatpack using these systems.

In consultation with NASA personnel, it was concluded that the experimental effort should be interrupted until a more precise and rigid welder frame could be fabricated. Inasmuch as such equipment development was beyond the scope and funding of the program, the work was undertaken by Technidyne at no cost to the Government. Experimental effort on the contract was interrupted for several months pending completion.

The frame, designed to accommodate both the lateral-drive and the torsional systems, is shown in Figure 7 with the lateral-drive system installed. The welding head was rigidly mounted to the upper triangular platen of the frame. Clamping force was applied by raising the anvil assembly with precision pneumatic pressure cylinders. Provision for horizontal alignment and centering was provided by an adjustable precision way-slide assembly in the anvil support (Figure 8).

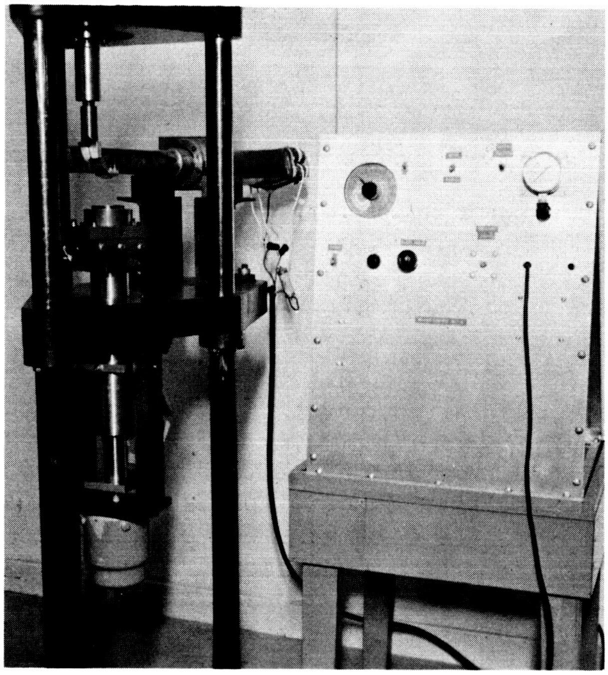


Figure 7

PRECISION FRAME WITH 17.5-KC LATERAL-DRIVE SYSTEM INSTALLED

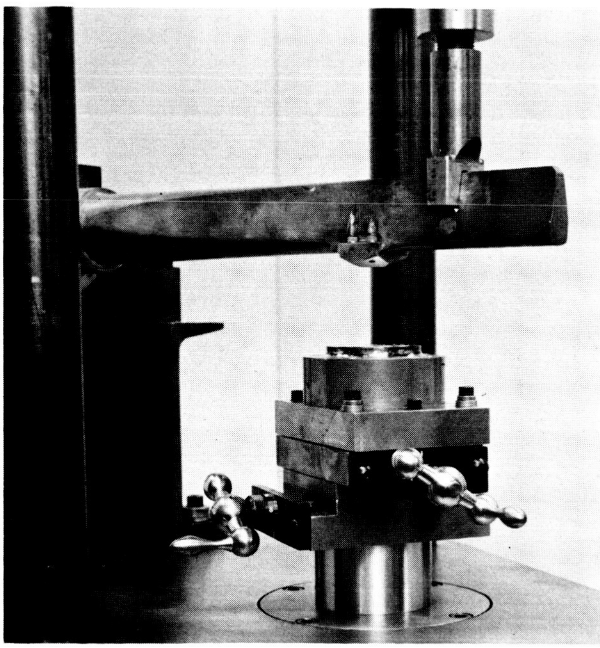


Figure 8

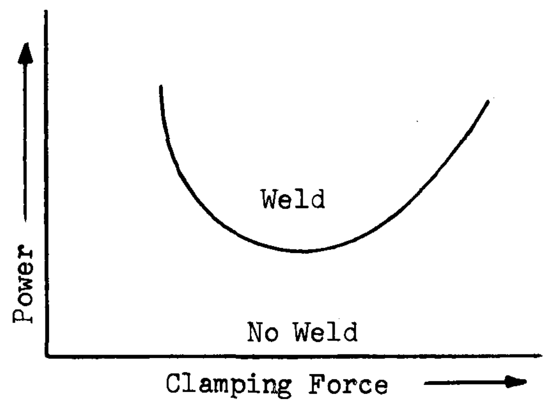
WAY-SLIDE ANVIL ASSEMBLY

IV. PROCEDURES

A. Welding Machine Settings

The threshold-curve technique was generally used to bracket welding machine settings of power, clamping force, and weld time for each flatpack-cover combination, although the settings thus indicated required modification because of the fragility of the flatpacks.

To construct a threshold curve, a reasonable value of weld time, usually less than 1 second, is first selected. Then, using an arbitrarily selected value of clamping force, welds are made at progressively decreasing values of electrical power input to the transducer, until the resulting welds no longer fail, when manually peeled, by tearout of the weld nugget. This establishes the minimum power at which effective welds can be made at that clamping force. The procedure is repeated at other clamping force values, and the results are plotted as a curve of power vs. clamping force, which is concave upward as shown below:



The minimum point on the curve establishes the clamping force at which welds are produced with least power (i.e., best impedance matching into the weldment). The total required welding energy is then a product of the indicated power and the weld time used. Increases in power with corresponding decrease in time, or vice versa, will provide the same total energy.

B. Evaluation Techniques

The hermetic quality of the welded flatpack assemblies was evaluated by helium-leak tests and hot-oil immersion tests. Representative weldments were also examined metallographically.

1. Helium-Leak Test

The 3/8-inch-square flatpack assemblies were subjected to helium-leak test using a VEECO Model MS-9AB mass spectrometer calibrated to a sensitivity of approximately 2×10^{-10} cc of helium per second at STP. The bottom cover of a welded package was punctured and the puncture connected to the input of the mass spectrometer, which produced a vacuum inside the flatpack. As a jet of helium gas was passed around the package, differential pressure (not exceeding 1 atmosphere) caused helium to flow through any leaks. The mass spectrometer detected the presence of helium molecules within the flatpack.

2. Hot-Oil Immersion

The 1/4-x-1/8-inch flatpack assemblies were tested by hot-oil immersion in accordance with MIL STD-202C, Condition A of Method 112. The welded packages were immersed in silicone oil (Dow Corning 200) heated to about 190°C. The heat created an internal pressure in the flatpack which tended to open passages through the weld and allow the escape of air. Leakage was detected by the presence of bubbles in the liquid.

3. Metallographic Examination

Selected flatpack assemblies were sectioned through the weld area, mounted, polished, and etched, and examined by means of a Vickers metallograph at magnitudes up to 500X.

V. ULTRASONIC WELDING OF 3/8-INCH-SQUARE FLATPACKS

Initial work was carried out with the 3/8-inch-square flatpacks, using the 15-kc torsional welder, to expose welding problems and establish conditions for bonding covers to the flatpack frames.

A. Non-Parallelism of Flatpack Surfaces

Successful ultrasonic welding of an annular configuration in a single pulse requires that the surface to be welded be reasonably flat and parallel to the welding surface. If the weldment member is supported on a flat anvil, as was the case with the flatpacks, the top or welding surface must be parallel to the bottom surface seated on the anvil. It immediately became apparent that the flatpacks obtained for the work did not have the degree of parallelism desired for such small-diameter welds, and that they were characterized by surface waviness and twist.

Twenty-four of the 3/8-inch-square flatpacks were selected at random and measured for surface and thickness irregularities. Measurements were made with a ball-point micrometer caliper (1/8-inch spherical radius ball) reading to the nearest 0.00025 inch. The flatpacks were supported on a surface plate and the periphery of each was scanned under the ball-point by rotating the flatpack through 360 degrees so that all four sides were measured. The measurements, presented in Table II, indicated that variations resulting from non-parallel surfaces, twist, and waviness were as much as ±0.0025 inch. Both visual inspection and thickness measurements showed that non-parallelism of the surfaces was the major factor contributing these variations, although waviness of the top surface of some samples was also significant.

In an effort to accommodate these irregularities, initial welding of the flatpacks was carried out with 0.006-inch 3003-H18 aluminum alloy covers, which it was thought might have sufficient malleability to deform under the welding forces. Machine settings were varied over a range of 2000 to 4000 watts electrical power input, 100 to 400 pounds clamping force, and 0.1 to 0.4 second weld interval. Complete peripheral welds were not obtained under these conditions.

Another approach used to compensate for non-parallel top and bottom surfaces was meticulous alignment of the anvil so that the top surface of the flatpack was parallel to the welding tip. By this means, one complete peripheral weld was obtained with a cover of 0.006-inch 3003-H18 aluminum alloy. However, this technique is impractical because it would require realignment for each flatpack. The experiment was performed only to

Table II

THICKNESS MEASUREMENTS ON 3/8-INCH-SQUARE FLATPACKS

	Total Deviation (inches x 0.001)			
No.	Side 1	Side 2	Side 3	Side 4
1	2	4	1	5
2	0.5	1.5	0	1
3	1	1.5	2	2
4	2	0.5	1	0.5
5	3.5	3.5	3	4.5
6	2	4.5	1	3
7	0	0.5	2.5	1
8	0.5	2	1.5	1
9	2	2	3	2
10	2	2	2	1.5
11	0.5	3	0.25	0.25
12	2	5	5	0.25
13	2	5	0.5	0.25
14	3	1.5	3	0.25
15	2	4	3	3
16	0.25	2	0.5	0.25
17	0.25	1	2	1.5
18	3	2	3.5	0.5
19	0.25	0.5	0.25	0.5
20	0	2	0.25	1
21	0	1.5	1.5	0.25
22	1	0.25	0	1
23	2	1	3	1
24	1.5	0.5	0.5	2

demonstrate that complete closures could be obtained with adequate alignment. Development of a self-aligning anvil was considered, but the design and development effort required was beyond the scope of the program, and this approach was not pursued.

The problem was discussed with Zell Products representatives, who indicated that it might be practical to fabricate a limited quantity of flatpacks with surfaces parallel within 0.001 inch, although this would require modification of their existing production tooling. Shortly after this consultation, Zell discontinued flatpack manufacture, and the higher precision flatpacks were not forthcoming.

Flatpacks with parallel surfaces were finally obtained by special processing at Technidyne of the as-received Zell flatpacks. Each flatpack was placed, with the top or welding surface down, on the magnetic chuck of a surface grinder, and the bottom surface was ground parallel to the top surface. Thickness measurements made on six typical samples after grinding (Table III) showed that thickness variation was reduced to less than 0.0005 inch, compared to 0.0025 inch before grinding.

Table III

RESULTS OF THICKNESS MEASUREMENTS AND MICROSCOPIC INSPECTION OF 3/8-INCH-SQUARE FLATPACKS AFTER GRINDING

Sample No.	Thickness (Inches)				Microscopic Inspection Cracks in Glass
	A	B	C	D	
70	0.042	0.042	0.042	0.042	None
71	.0415	.0415	.0415	.0415	None
72	.040	.0405	.041	.041	None
73	.040	.040	.040	.040	None
74	.036	.036	.036	.0355	None
75	0.0425	0.0425	0.0425	0.0425	None

A small number of special-precision flatpacks (variations less than 0.0001 inch) were prepared by hand-lapping the top surface prior to grinding the bottom. Lapping removed some of the surface irregularities and waviness on the frame, but also removed some of the gold plating. They were replated with gold by the supplier, Zell Products Incorporated, and checked for hermeticity. Of 19 flatpacks thus reprocessed, 8 were leaktight and 11 leaked through the glass seal (body). It appeared that the grinding wheeel had contacted the glass fillet at the edge of the bottom cover, causing the glass to crack. The grinding operation could have been refined, but it provided sufficient leaktight packages for preliminary investigation.

B. Welding of Aluminum Covers

Welding was performed with the 0.006-inch 3003-H18 aluminum alloy covers and the flatpacks that had been ground to a parallelism of ±0.0005 inch. Machine settings of 4000 watts electrical power to the transducers, 0.1 second weld interval, and 200 pounds clamping force produced bonding over most of the periphery.

Experience indicated that a thicker or softer cover should provide a slightly greater degree of deformation so as to accommodate the remaining waviness, and a softer aluminum alloy, 1145-O, of the same thickness (0.006 inch) was selected. Machine settings of 4000 watts, 0.25 second, and 200 pounds resulted in complete peripheral welds, but the samples were not leaktight. Microscopic examination showed small cracks in the substrate glass, which were attributed to cyclic vibratory strain occurring in the glass interlayer during welding. The peak stress was reduced by reducing the power to 2200 watts while increasing the weld time to 0.3 second. (Electrical energy input was thus reduced from 1000 watt-seconds to 660 watt-seconds.) Five of seven specimens prepared at these settings were helium leaktight when tested on the mass spectrometer. One of these specimens is shown in Figure 9.

C. Metallographic Examination of Aluminum Cover Welds

Two of the leaktight specimens prepared with the 1145-O aluminum alloy cover material were sectioned for study of metallographic characteristics. The representative photomicrograph shown in Figure 10 indicates that uniform bonding occurred between the gold-plated surface and the aluminum cover sheet. Voids or other imperfections that might impair the hermeticity of the package seal are not apparent. Shallow interpenetration of the faying surfaces can be observed, with fragmentation and dispersion of the aluminum oxide surface film along the bond interface. The dark band at the aluminum-gold interface was caused by the slightly different surface levels of the two materials, resulting from differing rates of metal removal during mechanical polishing. The shadow line thus produced obscures some of the interface detail.

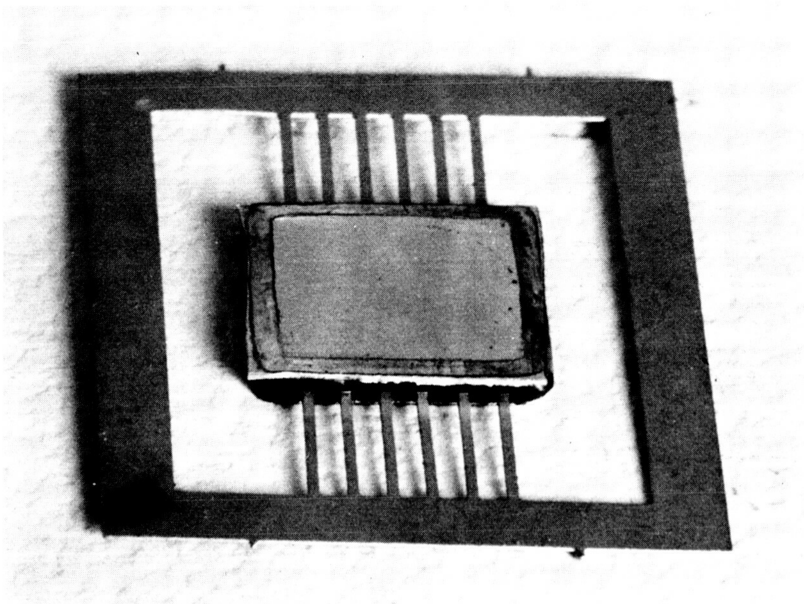


Figure 9

LEAKTIGHT 3/8-INCH-SQUARE FLATPACK
WITH ULTRASONICALLY WELDED COVER

Cover Material: 0.006-inch 1145-O Aluminum Alloy
Ultrasonic System: 15-kc Torsional

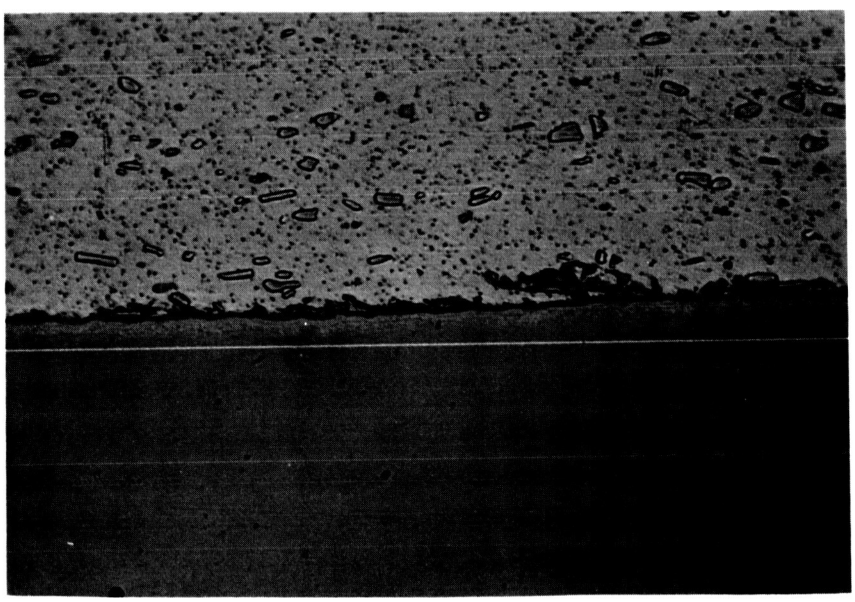


Figure 10

PHOTOMICROGRAPH OF ULTRASONIC WELD
BETWEEN GOLD-PLATED KOVAR AND ALUMINUM

Magnification: 500X
Etchant: 0.5% HF

The photomicrograph does not reveal the structure of the gold-plate layer and the Kovar substrate; the chemical etchant (0.5-percent hydrofluoric acid) attacked only the aluminum, and shadow lines similar to that produced at the joint interface are apparent at the boundaries between the harder dispersed-phase particles and the soft aluminum matrix.

D. Welding of Gold-Plated Kovar Covers

Gold-plated Kovar covers (supplied with the flatpacks) were welded to the flatpacks that had been lapped on the top surface before being ground on the bottom (these units had surface variations of less than 0.0001 inch). Using welding machine settings varied over a range of 1900 to 2500 watts, 0.35 to 0.6 second, and 275 to 300 pounds, bonding between the gold platings occurred only at the corners of the packages.

The available thickness of ductile material was then increased by inserting various interleafs: 0.0005-inch gold, 0.00015-inch gold, and 0.0003-inch 1100-H14 aluminum alloy. The 0.0005-inch gold interleaf yielded the most uniform bonding, but the peel strength obtained at the corners was greater than that on the sides. This preferential bonding was attributed to the geometry of the flatpacks, since the acoustic power delivered to the corners of the square ring weld is greater than that delivered to the midpoints of the sides.

A practical solution was sought by increasing the weld time, thus exposing the corners to slightly excess power in order to cause the weld to propagate along the sides. With the 0.0005-inch gold interleaf inserted, complete peripheral welds were achieved at 1.5 seconds, 2000 watts, and 275 pounds. Attempts to peel the covers induced fracture through the glass substrate, indicating the superior strength of the bonds.

The use of the interleaf may have been critical. The average thickness of the gold plating on the cover and on the flatpack was reported by the supplier to be 0.0002 inch. However, metallographic examination of one specimen welded without an interleaf showed that the gold plating on the frame was only 0.0001 inch thick, while that on the cover was 0.0006 inch thick. The observed difference is presumed to have existed in other samples also. The thin layer on the frame was restrained by the more rigid Kovar substrate and could not provide much plastic deformation.

Subsequent to the foregoing, only three of the leaktight, special-precision (parallel within 0.0001 inch) flatpacks remained. Gold-plated Kovar covers were welded to their frames at the above settings with the gold-foil interleaf inserted. One specimen was shown by helium leak test to be hermetically sealed.

E. Evaluation of Other Cover Materials

Three additional cover materials were evaluated by welding to the 3/8-inch-square flatpack: 0.005-inch commercially pure copper, annealed; 0.005-inch "A" nickel with a gold plating of 500 microinches for a total thickness of 0.006 inch; and 0.010-inch Alloy 180 (22 percent copper, 78 percent nickel).

Threshold curves for welding each material to gold-plated Kovar were constructed, as previously described, to determine the static clamping force required to produce coupling to the weldment. These curves were obtained by welding 0.11-inch-wide ribbons of the candidate cover material to 3/8-inch-square gold-plated covers. The selected weld times were 0.5 second for the copper and Alloy 180, and 1.0 second for gold-plated nickel. The threshold curves thus derived (Figure 11) show the optimum clamping forces for welding these cover materials to the flatpack material to be in the range of 500 to 600 pounds, well in excess of the 300-pound limit beyond which damage to the glass seal of the flatpack had occurred during welding of aluminum and gold-plated Kovar covers.

Covers of each of the three materials were welded to flatpacks that were leaktight after having been ground on the bottom surface to provide parallel surfaces within 0.0005 inch. Machine settings and results are summarized in Table IV. Although good bonding was obtained in some instances, leaktight specimens could not be produced. The high clamping forces and levels of energy required to bond these relatively hard materials induced fracture of the ceramic body, probably at the localized pressure points associated with the 0.0005-inch non-parallelism.

Welding was attempted using the 0.0005-inch gold-foil interleaf that had permitted complete peripheral bonding of the gold-plated Kovar covers. With these materials, use of the interleaf did not permit sufficient reduction of machine settings to allow reproducible bonding without damage to the glass body of the flatpack.

The investigation with the 3/8-inch-square flatpack showed that a leaktight package could be produced with covers of 0.006-inch 1145-0 aluminum alloy ultrasonically welded to this flatpack with the 15-kc torsional welder. Complete peripheral welds were also obtained with the Kovar covers using a 0.0005-inch gold interleaf.

Because the original supply of 150 flatpacks was consumed in these investigations, and efforts to procure additional packages for further investigations and for supplying samples to NASA were unsuccessful, further efforts were concentrated on the smaller flatpacks.

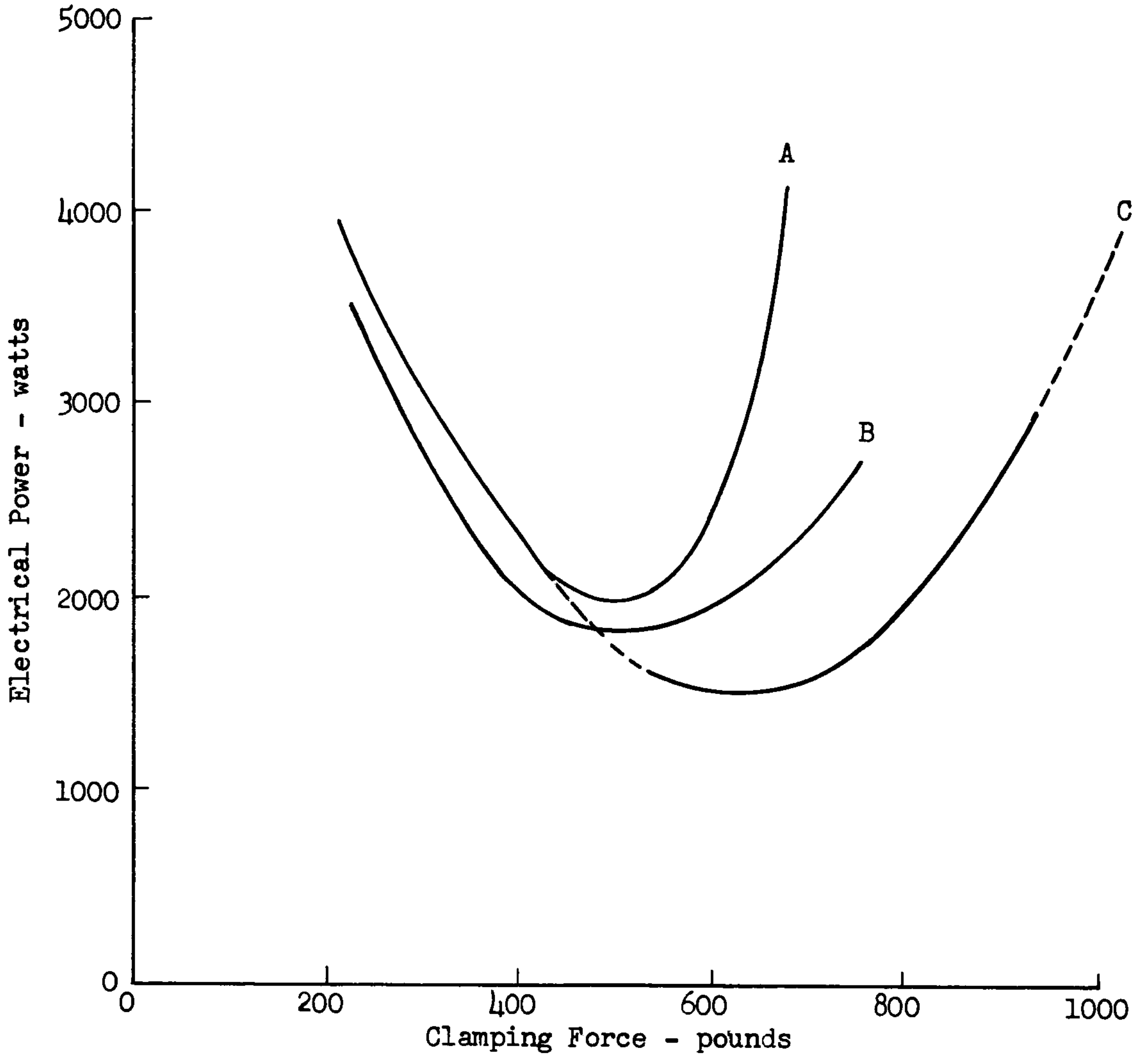


Figure 11

POWER-FORCE THRESHOLD CURVES FOR WELDING
COVER MATERIALS TO GOLD-PLATED KOVAR

A. 0.010-inch Alloy 180, t = 0.5 second
B. 0.005-inch Copper; t = 0.5 second
C. 0.006-inch Gold-Plated Nickel; t = 1.0 second

Table IV

WELDING COVERS OF COPPER, GOLD-PLATED NICKEL,
AND ALLOY 180 TO 3/8-INCH-SQUARE FLATPACKS

Cover Material	Welding Conditions: Clamping Force (pounds)	Power (watts)	Weld Time (sec)	Remarks
0.005" Copper	500	2900	0.5	Good bonding. Ceramic seal cracked.
	500	2900	0.4	Only 500 μ pump-down obtained. Crack in ceramic seal.
	500	2200	0.9	Complete weld. Bottom cover separated from ceramic seal.
	500	2200	0.5	Welded on only one edge. Ceramic seal cracked.
	300	3600	0.5	Good bonding. Ceramic seal damaged.
	225	3600	0.5	Partial bonding. Ceramic seal cracked.
	225	2900	0.5	Partial bonding. Ceramic seal cracked.
	225	2900	0.3	Good bonding along edges. Corners not bonded.
0.006" Gold-Plated 'A' Nickel	400	3800	0.5	Uniform bonding. Shattered seal.
	400	2000	0.5	Double pulse. Crack in seal.
	400	1000	1.5	0.0005" gold interleaf used. Good bonding; ceramic seal cracked.
	225	3800	0.5	Ceramic seal cracked.
	225	3000	1.0	One corner not bonded.
	225	3000	0.5	Double pulse. Non-uniform bonding. Ceramic seal cracked.
0.010" Alloy 180	300	4000	0.3	Ceramic body cracked.
		4000	0.2	No cracks. Cover easily peeled from frame.
		4000	0.2	Not leaktight. Only 100 μ pump-down pressure obtained.
		4000	0.1	No bonding.
	300	3000	0.5	Ceramic body cracked. About 75% of picture frame area bonded.

VI. ULTRASONIC WELDING OF 1/4-X-1/8-INCH FLATPACKS

Welding of the 1/4-x-1/8-inch flatpacks was carried out with both the 28-kc torsional and the 17.5-kc lateral-drive welders. On the basis of results obtained, the 17.5-kc lateral-drive welder, installed in the precision frame, was used for the final investigation and sample preparation.

A. Non-Parallelism of Flatpack Surfaces

Prior to welding, thickness measurements were made on representative 1/4-x-1/8-inch flatpacks. Since non-parallelism had been the major cause of thickness variation with the larger flatpacks, these measurements were made only at four discrete points on the flatpack frame. A standard ball-point micrometer caliper reading to the nearest 0.00025 inch was used.

Table V presents measurements on fourteen flatpacks from the group obtained from the Goddard Space Flight Center used in welding development. Table VI presents measurements on fourteen flatpacks from the group used in the final investigation, which were obtained from Texas Instruments domestic and England plants. Thickness variations were substantially less than those measured for the larger flatpacks. Half of the samples in each group showed variations of 0.0005 inch, and few exceeded 0.001 inch. None of these smaller packs were ground or lapped before welding.

B. Welding Development

1. Welding of Aluminum Covers

In order to ascertain a satisfactory clamping force for welding covers of 0.005-inch 3003-H18 aluminum alloy to the gold-plated Kovar frame, threshold curve data for welding the aluminum alloy to itself were obtained with both welding systems. The 28-kc torsional welder was equipped with a tip contoured for the 1/4-x-1/8-inch flatpack, providing a weld area of 0.039 square inch. The lateral-drive welder had a slightly larger weld area, 0.046 square inch. The resulting curves, shown in Figure 12, indicated an optimum clamping force in the vicinity of 350 pounds for both systems. A higher power level was indicated for the torsional system, attributed at least in part to the shorter weld time used.

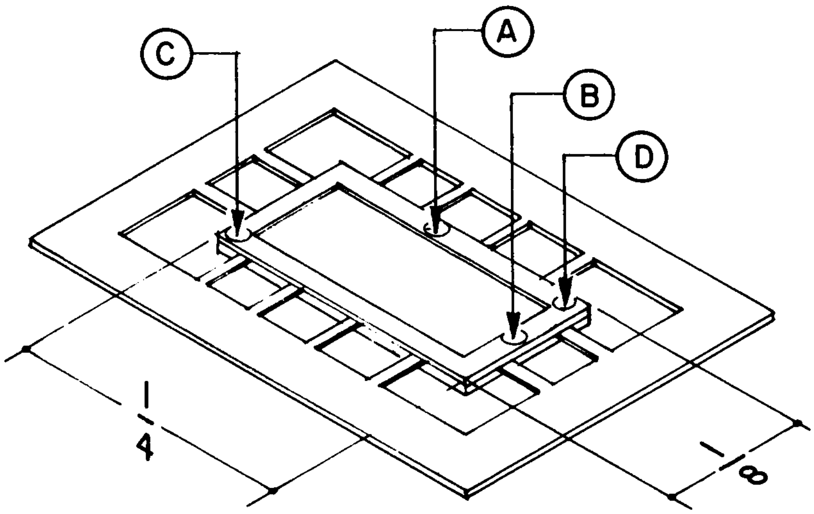


Table V

THICKNESS MEASUREMENTS ON TEXAS INSTRUMENTS
1/4- BY 1/8-INCH FLATPACKS

Sample No.	Thickness (inch) at Position: A	B	C	D	Maximum Difference (inch)
1	0.0335	0.0325	0.0340	0.0315	0.0025
2	0.0340	0.0335	0.0335	0.0335	0.0005
3	0.0345	0.0350	0.0340	0.0350	0.0010
4	0.0335	0.0340	0.0310	0.0340	0.0030
5	0.0360	0.0370	0.0350	0.0370	0.0020
6	0.0340	0.0340	0.0350	0.0340	0.0010
7	0.0350	0.0355	0.0355	0.0350	0.0005
8	0.0335	0.0335	0.0330	0.0335	0.0005
9	0.0350	0.0345	0.0345	0.0345	0.0005
10	0.0355	0.0350	0.0350	0.0350	0.0005
11	0.0335	0.0340	0.0335	0.0340	0.0005
12	0.0330	0.0320	0.0315	0.0325	0.0015
13	0.0335	0.0335	0.0330	0.0330	0.0005
14	0.0350	0.0345	0.0355	0.0340	0.0015

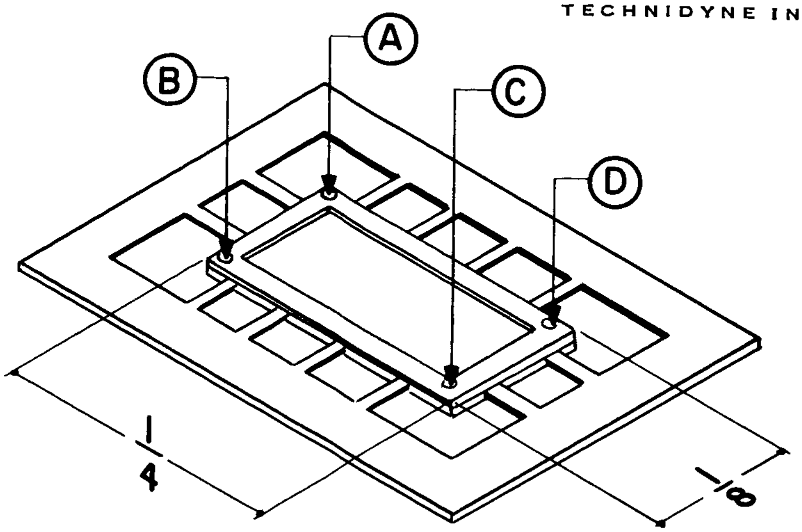


Table VI

THICKNESS MEASUREMENTS ON 1/4-X-1/8-INCH FLATPACKS
USED FOR FINAL SAMPLE PREPARATION

Package No.	Thickness (inch) at Position: A	B	C	D	Maximum Difference
103	0.0340	0.0330	0.0340	0.0340	0.001
104	.0325	.0330	.0320	.0325	.001
105	.0325	.0325	.0325	.0320	.0005
106	.0315	.0320	.0330	.0325	.015
107	.0330	.0330	.0330	.0328	.0002
108	.0330	.0330	.0335	.0335	.0005
109	.0335	.0345	.0345	.0340	.001
110	.0345	.0340	.0340	.0340	.0005
111	.0335	.0340	.0340	.0340	.0005
112	.0335	.0335	.0340	.0345	.0010
113	.0335	.0335	.0340	.0340	.0005
114	.0340	.0340	.0340	.0340	.0000
115	.0320	.0325	.0325	.0320	.0005
116	0.0340	0.0335	0.0335	0.0340	0.0005

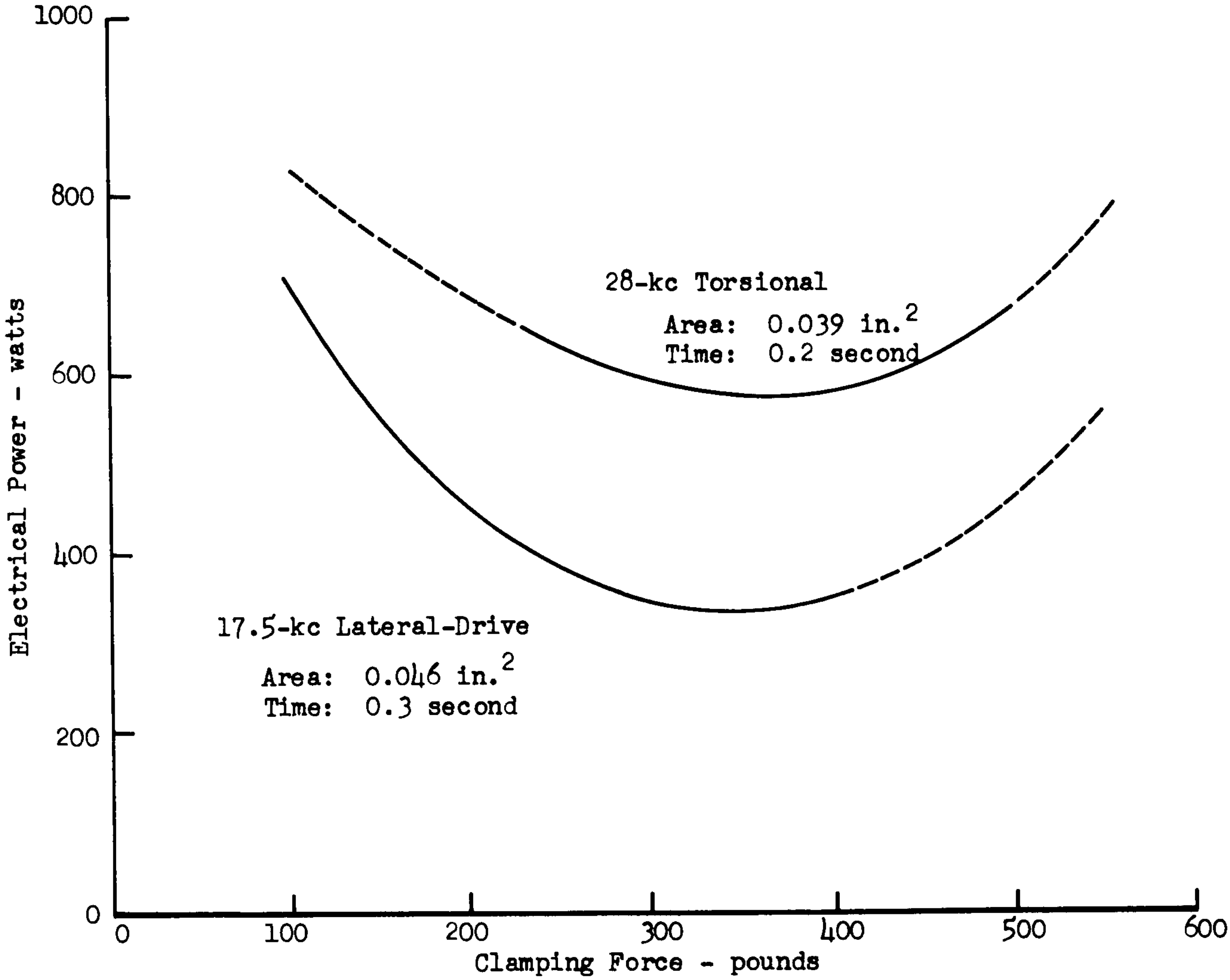


Figure 12

POWER-FORCE THRESHOLD CURVES FOR WELDING 0.005-INCH ALUMINUM ALLOY TO ITSELF WITH TWO WELDING SYSTEMS

Using the 28-kc torsional welder, covers of 0.005-inch 3003-H18 aluminum alloy were welded to several flatpacks (from the group listed in Table V) to determine if the typical non-parallelism of these packages could be overcome by preferential yielding of the aluminum cover. Typical results are presented in Table VII. Clamping forces in excess of 300 pounds produced bowing of the long sides of the flatpack, and loads of 400 pounds resulted in collapse of the flatpack sidewalls. Welding at 200 pounds clamping force resulted in collapse of the thin aluminum cover into the flatpack cavity.

During hot oil immersion tests on assemblies welded at 800 watts, 200 pounds, and 0.25 second, escaping air bubbles indicated small isolated regions of non-bonding, probably resulting from non-parallelism of the flatpack surfaces.

Table VII

WELDING COVERS TO UNGROUND 1/4-X-1/8-INCH FLATPACKS WITH THE 28-KC TORSIONAL WELDER

Cover Material: 0.005-Inch 3003-H18 Aluminum

Welding Machine Settings			
Clamping Force (lbs)	Power (watts)	Time (sec)	Remarks
150	800	0.25	Only partial welding because of misalignment.
200	800	0.25	Cover collapsed into flatpack cavity. Weld coverage uniform.
400	400	0.25	Flatpack deformed.

2. Cover Material Evaluation

Using the 17.5-kc lateral-drive welder, assemblies were welded with three cover materials: 3003-H18 aluminum alloy, gold-plated nickel, and gold-plated Kovar--all 0.005 inch thick. Typical results are presented in Table VIII.

Table VIII

WELDING COVERS TO UNGROUND 1/4-X-1/8-INCH
FLATPACKS WITH THE 17.5-KC LATERAL-DRIVE WELDER

Cover Material	Maximum Thickness Variation (inch)	Clamping Force (lb)	Power (watts)	Time (sec)	Remarks
Gold-plated Kovar	0.0010	170	850	0.3	Complete weld not obtained after 6 rotations of flat-pack.
Gold-plated Kovar	0.0030			0.3	0.0005-inch gold interleaf used. Results same as above.
Gold-plated Nickel	0.0005			0.3	Two welding pulses with 180° rotation required to cover area. Small leak (hot oil test).
3003-H18 Aluminum	0.0010			0.3	Uniform coverage. Small leak around one lead.
3003-H18 Aluminum	0.0020	170	850	0.1 0.2	Two successive pulses. No leaks during 5-minute immersion in hot oil (180°C).

Complete peripheral bonding was obtained only by repositioning (rotation) and repeat welding, because of the thickness variations and because the welder could not be aligned precisely enough in its original frame to obtain sufficiently accurate centering or planar alignment. As in the earlier work with the larger flatpacks, non-parallel surfaces presented greater difficulties with harder cover materials (nickel and Kovar). A leak-tight closure (by hot oil immersion test) was obtained with one rotation between an aluminum cover and a sample having a 0.0020-inch thickness difference, whereas a complete weld could not be obtained with six rotations between gold-plated Kovar and a flatpack having the same thickness difference.

Subsequent welding with gold-germanium preforms inserted between the gold-plated Kovar covers and the flatpack did not significantly facilitate bonding.

3. Welding With a Precision Anvil Fixture

Welding of gold-plated Kovar covers was then carried out with the precision anvil fixture (described on page 8) designed to provide precise positioning and restraint of the 1/4-x-1/8-inch flatpack during welding.

Covers of 0.003-inch gold-plated Kovar were welded at 850 watts, 240 pounds, and weld times from 0.1 to 0.7 second. The samples showed small leaks in the hot oil test, and subsequent inspection of the weld interface after removing the cover revealed non-bonded areas, attributable to imperfect alignment with the welding tip.

Inspection of the welded packages prior to leak-testing revealed that an occasional flat lead was broken off close to the body. Such breakage was attributed to high-amplitude vibration of the flatpack body while clamped in the fixture, which resulted in fatigue-fracture of the flat leads. Rotating the anvil 90 degrees and 45 degrees to the vibratory direction did not reduce the incidence of lead fracture, and further effort with the fixture was discontinued.

The welding investigation up to this point had indicated that leaktight packages could possibly be obtained with the 1/4-x-1/8-inch flatpack using an aluminum alloy cover. It was apparent, however, that the mounting frames and clamping force systems of the welders did not provide the precision in alignment and force application required for flatpack encapsulation.

The work was therefore interrupted pending completion of the precision frame and clamping force system (page 12).

C. Final Sample Preparation

The objective adopted for the concluding work on the program was to obtain a leaktight cover seal, having good mechanical peel strength, without resorting to grinding or other corrective measures involving modification of the flatpack.

1. Materials

This work was carried out with 1/4-x-1/8-inch flatpacks obtained from Texas Instruments domestic and England plants, which had shown relatively low thickness variation (Table VI). No leak tests were made on the packs prior to welding; hence the integrity of the glass seals was unknown.

Because aluminum covers had been shown previously to yield preferentially at the low clamping forces implicit with fragile glass components, two aluminum alloy covers were selected: 0.004-inch 1145-H19 and 0.006-inch 5154-H18. Preliminary work indicated welds with the 1145 alloy to be inferior, and all the results here reported were obtained with covers of 0.006-inch 5154-H18 aluminum alloy.

2. Equipment

The lateral-drive welding system was selected for this work because it provided a greater available power range (2000 watts) than the small torsional system (1200 watts). Also, preliminary work with this system mounted in its original frame had produced leak-tight closures with minimum deformation and distortion of aluminum covers. The system was mounted in the new precision frame.

The welding tip used had a flat solid face 1/4 by 1/8 inch, later enlarged for easier operation by grinding the face down by 1/16 inch. Previous work in which the tip was oriented on the coupler so that the axial vibration occurred parallel to either the long or the short dimension of the frame had resulted in measurable bowing of the frame sidewalls. Consequently in this later arrangement the tip was installed with its diagonal axis parallel to the direction of vibration. With the flatpack similarly oriented beneath the tip, there was substantially less deformation of the frame during welding.

No anvil fixture was used, and the flatpack was held in position on the anvil surface with plastic tape. The tape effectively damped the vibration induced in the leads during welding, preventing the fatigue failure previously observed.

3. Machine Settings and Results

Table IX presents the welding machine settings and results of this final sample preparation. Clamping forces of 180 and 200 pounds were used. This narrow range was imposed by welding considerations and by the load-bearing strength of the flatpack. The minimum clamping force at which 0.004-inch 5154-H18 aluminum could be welded to gold-plated Kovar was approximately 180 pounds. At higher forces, where better weld quality was achieved, the glass lead-through seals cracked, and at still higher clamping forces progressive deformation (flattening) of the flatpack was observed.

Ultrasonic power and welding time was varied to produce a range of energy levels from 160 to 400 watt-seconds. At non-optimum clamping forces, ultrasonic energy is not efficiently utilized because of impedance mismatch, and proportionally more power is required to achieve equivalent welding results.

Table IX

FINAL FLATPACK WELDING

Cover Material: 0.006-Inch 5154-H18 Aluminum Alloy

Sample No.	Welding Machine Settings: Power (watts)	Clamping Force (lb)	Weld Time (sec)	Weld Energy (watt-seconds)	Leaked in Immersion Test: Cover	Glass Seal
118	1000	180	0.2	200	Yes	No
124	800	200	0.3	240	No	Yes
128		200	0.4	320	Yes	No
132		180	0.3	240	Yes	No
134		200			Yes	Yes
135					No	Yes
136					No	No
137					No	Yes
139						
140	800			240		
141	900			270		
143						
146						
147						
148					No	Yes
149	900			270	Yes	No
150	800			240	Yes	No
151	1000			300	No	Yes
152	1000			300	Yes	No
153	1200			360	No	Yes
154	1000			300	Yes	No
155	1000			300	Yes	No
156	1000	200	0.3	300	No	Yes
157	1600	180	0.1	160	Yes	No
158	1000	200	0.4	400	No	Yes
159	900		0.3	270	No	Yes
160					Yes	No
161					Yes	No
162					Yes	No
163					No	Yes
164					No	Yes
165	900			270	Yes	No
167	1000	200		300	Yes	No
168		180			Yes	No
170					No	Yes
171						
172						
173	1000	200	0.3	300	No	Yes

The results of oil immersion leak tests on the assembled packages are shown in the last two columns of Table IX and are summarized in Table X. Of the 35 packages welded at 200 pounds, 63 percent had a leaktight cover seal. However, 66 percent leaked through the glass seal, presumably from the steady clamping force or vibratory strain damage during welding. Parts were not available to make sufficient assemblies for statistical analysis of the results.

Table X

SUMMARY OF FINAL WELDING DATA

Clamping Force (lb)	Weld Energy (watt-sec)	No. Samples Made	Leak-tight Covers	Leak-tight Glass	Leak-tight Samples	Percent Leaktight Covers
180	160-300	4	0	4	0	0
200	240	8	6	2	1	75
200	270	13	8	5	0	62
200	300	11	6	4	0	55
200	320-400	3	2	1	0	67

Figure 13 shows a package that was leaktight both through the cover weld and through the glass seal.

Twenty-five of the welded packages were selected for submission to the Goddard Space Flight Center.

In this concluding aspect of the study, reproducible and reliable closures were not achieved with presently available equipment and methods, because of limitations imposed on the selection of welding machine settings by the construction and fragility of the flatpack in its present state of development.

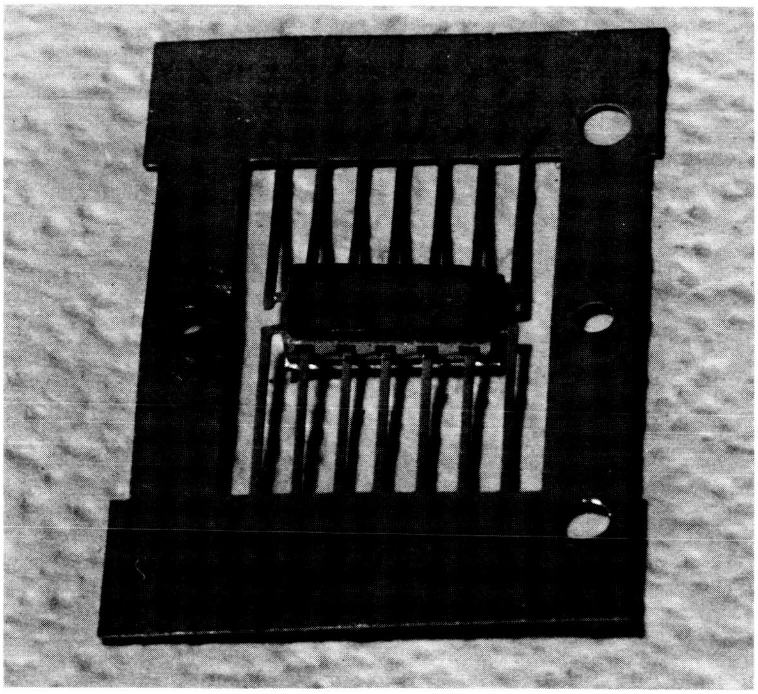


Figure 13

LEAKTIGHT 1/4-x-1/8-INCH FLATPACK WITH
ULTRASONICALLY WELDED COVER

Cover Material: 0.004-inch 5154-H18 aluminum
Ultrasonic Welder: 17.5-kc lateral-drive

VII. CONCLUSIONS AND RECOMMENDATIONS

Ultrasonic torsional and lateral-drive welding techniques were demonstrated to be capable of hermetically sealing covers to flatpack integrated circuits, but satisfactory seals were not reproducibly achieved using flatpacks of current design and with available welding equipment. The fragile glass seal in the flatpacks imposed limitations on the values of clamping force and vibratory power that could be used, making it difficult to achieve complete peripheral bonding without cracking the glass. Further difficulties were introduced by thickness variations and non-parallelism between the top and bottom surfaces of the flatpacks.

With the 3/8-inch-square flatpack, complete bonding of five out of seven samples was achieved with a soft aluminum cover after the back surface had been ground parallel to the welding surface (within ± 0.0005 inch). In addition, one leaktight package out of three was obtained with a gold-plated Kovar cover and a flatpack that had been lapped on the welding surface as well as ground on the back.

The grinding approach was not pursued with the smaller 1/4-x-1/8-inch flatpacks because it was desired to obtain leaktight seals without modifying commercially available flatpacks. Most of these smaller welded assemblies exhibited leaks either through the weld or through the glass seal.

Since the difficulties were not associated with welding the desired materials in the proper geometries, further development in ultrasonic welding or in flatpack design should make ultrasonic cover welding practical. A welding surface parallel to the welding tip could be provided either by a self-aligning anvil or by a flatpack with more nearly parallel surfaces. Although the latter development appears unlikely, other possible changes in flatpack design would facilitate ultrasonic welding. For example, a new flatpack developed by Texas Instruments has a Kovar body with an integral flange that could be supported by an anvil fixture during welding. Thus there would be no direct loading on the ceramic base. A projection on the flange (provided for resistance welding of the cover) would eliminate problems associated with non-parallelism and surface waviness.

An alternate approach to ultrasonic welding of flatpacks of the current castellated design might offer an avenue for improved flatpack construction. Metallographic examination by Texas Instruments of the castellated flatpack used in this program revealed glass between the frame and the bottom cover. Apparently resistance stitch welding of these components distorts the bottom cover sufficiently to allow glass to flow between the edge of the frame and the cover during the lead-through sealing operation. Subsequent welding of the top cover puts a direct loading on the glass at points where it extends under the frame. Either ultrasonic welding or resistance welding (unless electrode forces are maintained below 80 grams) may crack the glass, destroying the seal. Ultrasonic welding of the bottom cover could provide a complete seal between the bottom cover and the frame without heat distortion, so that glass could not flow between them.

APPENDIX I

EFFECT OF INCREASED FREQUENCY ON ULTRASONIC POWER DELIVERY OF TORSIONAL WELDERS

The following well-known equations hold for a shear wave (torsional vibratory excitation of an acoustic member) propagated along a rod (diameter is $\ll \lambda/8$).

$$C_r^2 \frac{\partial^2 \theta}{\partial x^2} \qquad \frac{\partial^2 \theta}{\partial t^2} \tag{1}$$

where $C_r = \sqrt{\omega/\rho}$,

μ = shear modulus - dynes/cm^2,

ρ = density - gm/cm^3,

and Hooke's Law equation is

$$T = \frac{-\pi\omega a^4}{2} \frac{\partial \theta}{\partial x} , \tag{2}$$

connecting the torque (T) and shearing strain ($\partial\theta/\partial x$) for the case of a circular rod of radius (a).

Unless the load exactly matches the impedance of the coupling system, torsional waves are reflected from the load toward the transducer, giving rise to a standing-wave pattern along the transmitting coupler. If an origin for x is chosen at a point of maximum angular displacement, such as the point of coupling of the terminal element of a torsional welder to the weldment, and a positive direction is chosen toward the load, the pattern of standing waves on the coupler is given by:

$$\theta = \theta_+ e^{j(\omega t - kx)} + \theta_- e^{j(\omega t + kx)} \tag{3}$$

where $k = 2\pi/\lambda = \omega/C_r$

θ_+ = amplitude of wave traveling toward load,

θ_- = amplitude of reflected wave traveling toward transducer.

The real part of Equation (3) is given by the expression

$$\theta = \theta_+ \cos(\omega t - kx) + \theta_- \cos(\omega t + kx). \tag{3a}$$

The angular velocity at any point is found from the real part of the time derivative of Equation (3) as follows:

$$\dot{\theta} = \frac{\partial \theta}{\partial t} = j\omega\theta \tag{4}$$

$$\text{RP of } \dot{\theta} = -\omega\theta_{+}\sin(\omega t-kx) + \theta_{-}\sin(\omega t+kx). \tag{4a}$$

The torque is obtained from

$$T = \left(-\frac{\pi\omega a^4}{2}\right)\frac{\partial \theta}{\partial x},$$

where $\frac{\partial \theta}{\partial x}$ is found from the real part of the space derivative of Equation (3), namely:

$$\frac{\partial \theta}{\partial x} = \theta_{+}k\sin(\omega t-kx) - \theta_{-}k\sin(\omega t+kx). \tag{5}$$

The instantaneous power passing any point is determined by

$$P = (\text{RP of } T) \times (\text{RP of ang. vel.}), \tag{6}$$

giving

$$P = \frac{\pi\omega a^4}{2} k\omega \left[\theta_{+}^2\sin^2(\omega t-kx) - \theta_{-}^2\sin^2(\omega t+kx)\right]. \tag{7}$$

The time average power delivered is then:

$$\bar{P} = \frac{1}{2}\frac{\pi\omega a^4}{2}\omega k(\theta_{+}^2 - \theta_{-}^2)$$

or

$$\bar{P} = \left(\frac{1}{2}A\rho C_r\right)\frac{a^2}{2}\omega^2(\theta_{+}^2 - \theta_{-}^2), \tag{8}$$

where $A = \pi a^2$ = area of the wave guide.

The standing-wave pattern is characterized by maximum and minimum values of angular displacement, and these have magnitudes

$$\Theta_{max} = \Theta_+ + \Theta_- \text{ , and}$$

$$\Theta_{min} = \Theta_+ - \Theta_- \text{ .}$$

We have, therefore, that the delivered power can be expressed by

$$P = \frac{1}{2}(A\rho C_r)\ \frac{a^2}{2}\ \omega^2 \Theta_{max}\ \Theta_{min}.$$

If we define the standing wave ratio as $S = \Theta_{max}/\Theta_{min}$, then

$$\overline{P} = (\frac{1}{2}\ A\rho C_r)\omega^2\ \frac{a^2}{2}\ \frac{\Theta^2_{max}}{S}\ . \tag{9}$$

In summary, the power that can be delivered depends upon the acoustic impedance properties of the material ($A\rho C_r$), the square of the angular displacement Θ_{max}, the square of the radius (a), and the square of the frequency.

In the case of welding flatpacks, the friable glass substrate in the pack has a strain limit beyond which fragmentation or cracking is likely to occur. Since the applied ultrasonic strain is proportional to ($a\Theta$), the power that can be applied for welding has a limit which is proportional to frequency squared, when other parameters are unchanged. Hence by approximately doubling the frequency (from 15 kc to 28 kc), the power for welding can be nearly four times higher for the same value of $a\Theta$, i.e., for the same vibratory strain applied to the glass substrate.